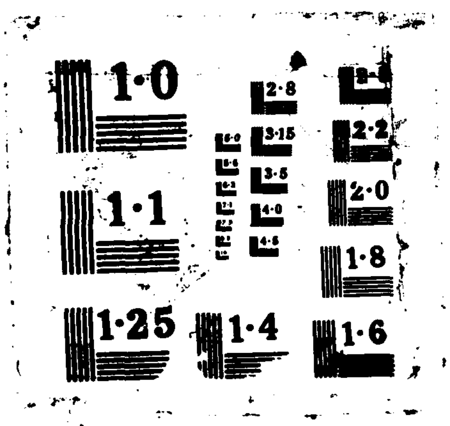
AD-A185 180   BATTLEFIELD FIRES FROM TACTICAL NUCLEAR WEAPONS(U)   1/1
PACIFIC-SIERRA RESEARCH CORP LOS ANGELES CA
W L WOODIE ET AL. 15 NOV 84 PSR-1453 DNA-TR-86-235
UNCLASSIFIED   DNA001-84-C-0271   F/G 19/11   NL


1·0
2·8
3·15
2·2
3·5
2·0
1·1
4·0
4·5
1·8
1·25
1·4
1·6

2

DNA-TR-86-235

BATTLEFIELD FIRES FROM TACTICAL NUCLEAR WEAPONS

W. L. Woodie
D. Remetch
R. D. Small
Pacific-Sierra Research Corporation
12340 Santa Monica Boulevard
Los Angeles, CA 90025-2587

15 November 1984

Technical Report

CONTRACT No. DNA 001-84-C-0271

Approved for public release;
distribution is unlimited.

THIS WORK WAS SPONSORED BY THE DEFENSE NUCLEAR AGENCY
UNDER RDT&E RMC CODE B3500844662 RM RK 00102 25904D.

Prepared for
Director
DEFENSE NUCLEAR AGENCY
Washington, DC 20305-1000

DNA PRINTING PLANT

CUT HERE AND RETURN

DISTRIBUTION LIST UPDATE

This mailer is provided to enable DNA to maintain current distribution lists for reports. We would appreciate your providing the requested information.

- ☐ Add the individual listed to your distribution list.
- ☐ Delete the cited organization/individual.
- ☐ Change of address.

NAME: ______________________________

ORGANIZATION: ______________________________

OLD ADDRESS	**CURRENT ADDRESS**

TELEPHONE NUMBER: ( ) ______________________________

SUBJECT AREA(s) OF INTEREST:

____

DNA OR OTHER GOVERNMENT CONTRACT NUMBER: ______________________________

CERTIFICATION OF NEED-TO-KNOW BY GOVERNMENT SPONSOR (if other than DNA):

SPONSORING ORGANIZATION: ______________________________

CONTRACTING OFFICER OR REPRESENTATIVE: ______________________________

SIGNATURE: ______________________________

Director
Defense Nuclear Agency
ATTN: [redacted] TITL
Washington, DC 20305-1000

Director
Defense Nuclear Agency
ATTN: [redacted] TITL
Washington, DC 20305-1000

UNCLASSIFIED
SECURITY CLASSIFICATION OF THIS PAGE

ADA185180

REPORT DOCUMENTATION PAGE

1a. REPORT SECURITY CLASSIFICATION: UNCLASSIFIED

1b. RESTRICTIVE MARKINGS:

2a. SECURITY CLASSIFICATION AUTHORITY: N/A since Unclassified

2b. DECLASSIFICATION / DOWNGRADING SCHEDULE: N/A since Unclassified

3. DISTRIBUTION / AVAILABILITY OF REPORT: Approved for public release; distribution is unlimited.

4. PERFORMING ORGANIZATION REPORT NUMBER(S): PSR Report 1453

5. MONITORING ORGANIZATION REPORT NUMBER(S): DNA-TR-86-235

6a. NAME OF PERFORMING ORGANIZATION: Pacific-Sierra Research Corporation

6b. OFFICE SYMBOL (If applicable):

7a. NAME OF MONITORING ORGANIZATION: Director Defense Nuclear Agency

6c. ADDRESS (City, State, and ZIP Code): 12340 Santa Monica Boulevard Los Angeles, California 90025-2587

7b. ADDRESS (City, State, and ZIP Code): Washington, DC 20305-1000

8a. NAME OF FUNDING / SPONSORING ORGANIZATION:

8b. OFFICE SYMBOL (If applicable):

9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER: DNA 001-84-C-0271

8c. ADDRESS (City, State, and ZIP Code):

10. SOURCE OF FUNDING NUMBERS

PROGRAM ELEMENT NO.	PROJECT NO	TASK NO.	WORK UNIT ACCESSION NO.
62715H	RM	RK	DH 846102

11. TITLE (Include Security Classification): BATTLEFIELD FIRES FROM TACTICAL NUCLEAR WEAPONS

12. PERSONAL AUTHOR(S): Woodie, W. L.; Remetch, D.; and Small, R.D.

13a. TYPE OF REPORT: Technical Report

13b. TIME COVERED: FROM 840615 TO 841115

14. DATE OF REPORT (Year, Month, Day): 841115

15. PAGE COUNT: 36

16. SUPPLEMENTARY NOTATION: This work was sponsored by the Defense Nuclear Agency under RDT&E RMC Code B35008446662 RM RK 00102 25904D.

17. COSATI CODES

FIELD	GROUP	SUB-GROUP
13	12	
15	7	

18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number): Fire Spread; Tactical Nuclear Weapons; Ignition; Thermal Ignition

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

Fires from tactical weapon exchanges in open terrain can be an important factor in assessing casualties and damage as well as managing troop deployments and operations. In addition to "prompt" thermal effects and fire starts, spread may also be an important factor on the battlefield. In this report, a model describing the initiation and spread of battlefield fires is presented. The initial ignition distribution is related to the weapon yield, slant range, local atmospheric properties, fuel type and ignition threshold. The fire spread analysis is based on an established U.S. Forest Service prediction algorithm. The present tactical ignition and fire spread (TIFS) model predicts the fire movement over variable terrains and accounts for ambient wind vectors, moisture, changing vegetation, and an arbitrary number of firebreaks. An example calculation illustrating the initial fire area and subsequent

20. DISTRIBUTION / AVAILABILITY OF ABSTRACT: ☐ UNCLASSIFIED/UNLIMITED ☒ SAME AS RPT. ☐ DTIC USERS

21. ABSTRACT SECURITY CLASSIFICATION: UNCLASSIFIED

22a. NAME OF RESPONSIBLE INDIVIDUAL: Sandra E. Young

22b. TELEPHONE (Include Area Code): (202) 325-7042

22c. OFFICE SYMBOL: DNA/CSTI

DD FORM 1473, 84 MAR — 83 APR edition may be used until exhausted. All other editions are obsolete.

SECURITY CLASSIFICATION OF THIS PAGE
UNCLASSIFIED

19. ABSTRACT (Continued)

spread in a complex terrain is presented for a 10-KT explosion. The results show the fires extending the effective weapon-damage radius, and identify regions to which the fires do not spread.

PREFACE

This report was prepared for the Defense Nuclear Agency (DNA) under contract DNA 001-84-C-0271 and supervised by Dr. Michael J. Frankel.

In previous Pacific-Sierra Research Corporation studies of fires started by nuclear weapon bursts, the physics of large area urban fires were considered. In this report, we examine fires started in battlefield areas by tactical nuclear bursts. The fires may spread far beyond the initial ignition zone. A computer program that calculates the initial ignition radius and the subsequent fire spread has been developed. A version of the tactical fire and spread program has been developed for inclusion in a battlefield assessment algorithm.

This report was presented at the DNA Conference on Large Scale Fire Phenomenology, September 1984, in Gaithersburg, Maryland, and will appear in the conference proceedings.

CONVERSION TABLE

Conversion factors for U.S. Customary to metric (SI) units of measurement

MULTIPLY → / TO GET ←	BY → / BY ←	TO GET → / DIVIDE ←
angstrom	1.000 000 X E -10	meters (m)
atmosphere (normal)	1.013 25 X E +2	kilo pascal (kPa)
bar	1.000 000 X E +2	kilo pascal (kPa)
barn	1.000 000 X E -28	meter^2 (m^2)
British thermal unit (thermochemical)	1.054 350 X E +3	joule (J)
calorie (thermochemical)	4.184 000	joule (J)
cal (thermochemical)/cm^2	4.184 000 X E -2	mega joule/m^2 (MJ/m^2)
curie	3.700 000 X E +1	*giga becquerel (GBq)
degree (angle)	1.745 329 X E -2	radian (rad)
degree Fahrenheit	$t_K = (t°f + 459.67)/1.8$	degree kelvin (K)
electron volt	1.602 19 X E -19	joule (J)
erg	1.000 000 X E -7	joule (J)
erg/second	1.000 000 X E -7	watt (W)
foot	3.048 000 X E -1	meter (m)
foot-pound-force	1.355 818	joule (J)
gallon (U.S. liquid)	3.785 412 X E -3	meter^3 (m^3)
inch	2.540 000 X E -2	meter (m)
jerk	1.000 000 X E +9	joule (J)
joule/kilogram (J/kg) (radiation dose absorbed)	1.000 000	Gray (Gy)
kilotons	4.183	terajoules
kip (1000 lbf)	4.448 222 X E +3	newton (N)
kip/inch^2 (ksi)	6.894 757 X E +3	kilo pascal (kPa)
ktap	1.000 000 X E +2	newton-second/m^2 (N-s/m^2)
micron	1.000 000 X E -6	meter (m)
mil	2.540 000 X E -5	meter (m)
mile (international)	1.609 344 X E +3	meter (m)
ounce	2.834 952 X E -2	kilogram (kg)
pound-force (lbs avoirdupois)	4.448 222	newton (N)
pound-force inch	1.129 848 X E -1	newton-meter (N·m)
pound-force/inch	1.751 268 X E +2	newton/meter (N/m)
pound-force/foot^2	4.788 026 X E -2	kilo pascal (kPa)
pound-force/inch^2 (psi)	6.894 757	kilo pascal (kPa)
pound-mass (lbm avoirdupois)	4.535 924 X E -1	kilogram (kg)
pound-mass-foot^2 (moment of inertia)	4.214 011 X E -2	kilogram-meter^2 (kg·m^2)
pound-mass/foot^3	1.601 846 X E +1	kilogram/meter^3 (kg/m^3)
rad (radiation dose absorbed)	1.000 000 X E -2	**Gray (Gy)
roentgen	2.579 760 X E -4	coulomb/kilogram (C/kg)
shake	1.000 000 X E -8	second (s)
slug	1.459 390 X E +1	kilogram (kg)
torr (mm Hg, 0° C)	1.333 22 X E -1	kilo pascal (kPa)

*The becquerel (Bq) is the SI unit of radioactivity; 1 Bq = 1 event/s.
**The Gray (Gy) is the SI unit of absorbed radiation.

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

SECTION 1
INTRODUCTION

Weapon systems are vulnerable to fire damage; however, there are currently no algorithms available to analyze this threat. Traditionally, there has been considerable uncertainty associated with the prediction of fire effects, and thus a reluctance to account for battlefield fires. In some cases, localized fires can spread large distances, and influence a battle area for a prolonged period of time.

On the nuclear battlefield, fires and fire spread may be a much greater threat. The thermal flash (even from low-yield weapons) can endanger equipment and personnel at large distances from the burst (especially for airbursts), and fire starts over large areas may result. The occurrence of sustainable ignitions depends on many factors, only some of which are weather dependent. Enough thermal energy is available such that ignitions are likely to occur, despite snow cover or precipitation. Furthermore, it is possible that these fires may spread from the initially ignited areas, greatly increasing the threat.

A large number of ignitions does not imply spread. However, should the fires spread, damage radii may be greatly increased, positions threatened, and operations restricted by the course and anticipated arrival time of the fire front. Also, smoke from either fixed or spreading fires might conceal operational movements, limit the use of optical imaging devices, and in general, influence battle management.

Conditions at the time of burst may not favor either an extensive ignition distribution or fire spread from the initial burning area. In western Europe, for example, fire spread is not probable during most of the year. Snow cover or wet conditions reduce the probability of fire spread. Nevertheless, periods of dryness favoring extensive spread can occur in normal weather patterns.

In this report, we summarize the development of a fire initiation and fire spread model for the nuclear battlefield. Although this study represents only a first battlefield fire model, the results indicate the potential effect with a fair degree of confidence. The model was developed using established routines that calculate wildland ignitions from a prescribed nuclear burst, and fire spread in an arbitrary terrain. The spread calculations are based on tested methcds and routines developed by the U.S. Forest Service for a variety of vegetations, terrains, and weather conditions.

In Sec. 2, the fire-start model is described. The spread prediction method is outlined in Sec. 3, and an example calculation is presented in Sec. 4.

SECTION 2
INITIAL IGNITIONS

Fire starts from a nuclear burst are influenced by the weapon parameters, vegetation and terrain, and weather conditions. All are important variables and not completely independent. For example, shadowing by forest stands or terrain features can reduce the ignition radius for very low (or surface) heights of burst.

In the tactical ignition and fire spread code (TIFS) we have developed, standard methods are used to predict (thermal) fire starts. There are, nevertheless, several approximations in the treatment of initial ignitions. Blast modification of the fuel bed and subsequent changes in the fire-start distribution are not considered. In general, such effects are not well modeled. The transport of flaming material from high overpressure areas may increase the number of ignitions at larger radii, assuming of course that the nascent ignitions are maintained. It is not clear, however, that such redistribution occurs. It also has been argued (and demonstrated in simple shock-tube tests) that the blast wave may actually blow out ignitions in high overpressure regions. Both of those effects support an annular fire hypothesis, and make subsequent fire spread likely.

Another blast modification of the fuel bed involves stripping of branches and toppling of trees (in high overpressure regions). A layering of live material over dead fuels results. Since live fuels do not usually sustain ignitions, the number of fire starts may be overestimated.

Other factors also modify forest ignitions. The canopy shields dead fuel material on the forest floor from the thermal radiation. Thus, ignitions will probably be spotty (although extensive) and dependent on season and foliage. If there is extensive dead material in the trees, crown fires are likely. Although not unusual, such fires do not occur often. It is also possible that the vapor (steam) from desiccation of the canopy could absorb some of the thermal radiation

and limit the number and extent of ignitions. This, however, may be a more important consideration for multiple burst attacks.

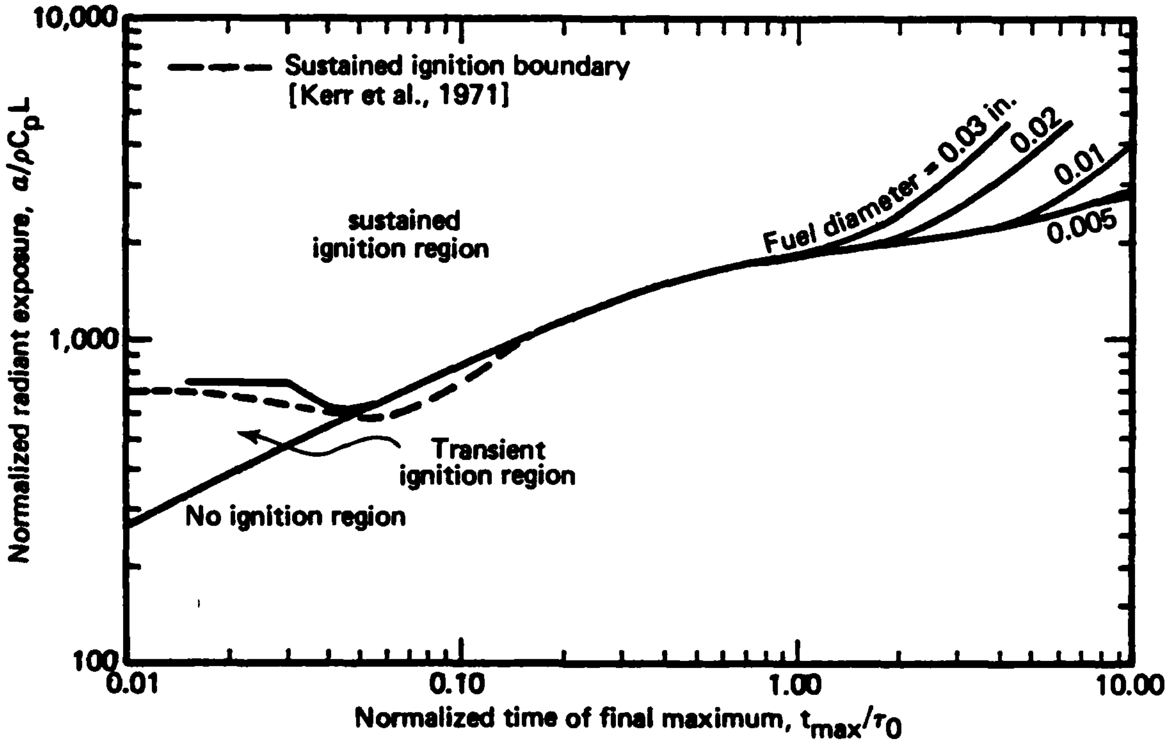
Although there are several unresolved issues, each of which warrants research, a large number of ignitions are probable. For fuel beds other than forests (such as brush, grass fields, croplands, etc.), many of the modifying effects do not significantly influence the fire-start distribution.

The type of vegetation, in particular its ignition threshold, is the second principal parameter needed to determine the fire-start distribution. Threshold levels have been determined experimentally for many fuels, and parameter influences such as yield, orientation, dimensions, albedo, have been investigated. Sufficient information is available to prescribe ignition conditions for most wildland fuels; however, more data would be useful.

Moisture is an important variable both for the calculation of sustained fire starts and prediction of fire spread. It is doubtful there would be large numbers of ignitions if there is heavy precipitation or snow cover. Similarly, the fire intensity and the probability of fire spread depend on the absorbed fuel moisture. At some level (moisture of extinction), fires do not spread. The amount of fuel moisture can vary significantly with the weather--principally with the frequency and amount of precipitation. For most applications, it is the moisture levels in the 1- and 10-h time lag classes (fuel sizes to 1 in.) that are important. Although in this first TIFS model, only a simple moisture correction based on humidity is used, the more elaborate National Fire Danger Rating System (NFDRS) method could be implemented.

The surface heating experienced by thin tinder fuel elements during a specified exposure is described by one universal function over a wide range of yield and fuel parameters. That function, shown in Fig. 1 [Kerr et al., 1971*], is built into the current computer model. For a given normalized fireball duration (pulse duration divided by

* See Table 4-2.



Source: Kerr et al. [1971].

Figure 1. Ignition thresholds for black α-cellulose exposed to simulated weapon pulse.

the thermal relaxation time of the fuel particle), Fig. 1 indicates the normalized radiant exposure required to raise the surface of the fuel to ignition temperature.

The physical parameters of the fuel particles needed to predict ignition criteria have been measured in previous studies [Kerr et al., 1971]. The three parameters used in the TIFS ignition model include (1) the thermal relaxation time, τ_0 sec; (2) the normalized specific heat $\rho C_p L$ (cal/cm^2-^{o}C); and (3) the average absorption coefficient A (dimensionless). Values for some typical forest fuels are shown in Table 1 [Kerr et al., 1971]. Predicted and measured ignition thresholds for those fuels agree to within ±30 percent.

An ignition decision in TIFS is computed as follows. First, based on the particular fuel thermal relaxation time τ_0, the ratio t_{max}/τ_0 is evaluated. The source parameter t_{max} is the time to peak radiant intensity and is given by [Glasstone and Dolan, 1977]

Table 1. Material parameters for ignition determination of typical weathered wildland fuels.

Fuel Type	L Thickness (cm)	ρ Specific Gravity	τ_0 Relaxation Time (s)	$\rho C_p L$ Normalized Specific Heat (10^{-3} cal/°C cm^2)	A Absorbtivity (dimensionless)
Cheatgrass leaves	0.011	0.25	0.05	0.82	0.3
Wheat straw	0.037	0.35	0.64	3.89	0.6
Beech leaves	0.009	0.39	0.04	1.05	0.6
Chestnut oak leaves	0.018	0.37	0.15	2.00	0.8
Rhododendron leaves	0.025	0.50	0.32	3.75	0.8
Shortleaf pine needles	0.058	0.52	1.73	9.05	0.8
Engleman spruce leaves	0.074	0.56	2.87	12.40	0.7

$$t_{max} = 0.043W^{0.43}\left(\frac{\rho}{\rho_0}\right)^{0.42} \quad s \quad , \tag{1}$$

where W is the yield in kilotons, and ρ/ρ_0 is the air density at the burst point normalized to the sea level value. From Fig. 1, the required normalized radiant exposure T_{req} for sustained ignition is determined. Using the absorption coefficient and the normalized specific heat of the fuel, the value of Q_{req}, the incident radiant exposure (cal/cm^2) needed to ignite the dry fuel is determined. In order to account for the moisture content of the fine dead fuel, the radiant exposure needed for ignition of dry fuel is increased by a factor $(1 + \omega/2)$ [Kerr et al., 1971], where ω is the local relative humidity. Thus, for moist fuel the required radiant exposure is

$$Q_{req}^{wet} = Q_{req}^{dry}\left(1 + \frac{\omega}{2}\right) . \tag{2}$$

The delivered radiant exposure Q_{del} is calculated using the local atmospheric visibility conditions and slant range. If Q_{del} is greater than Q_{req}, ignition occurs; for smaller values, ignitions are not sustained.

The delivered radiant exposure [Small and Brode, 1983], modified by an exposure function $P_e(\theta)$, is given by

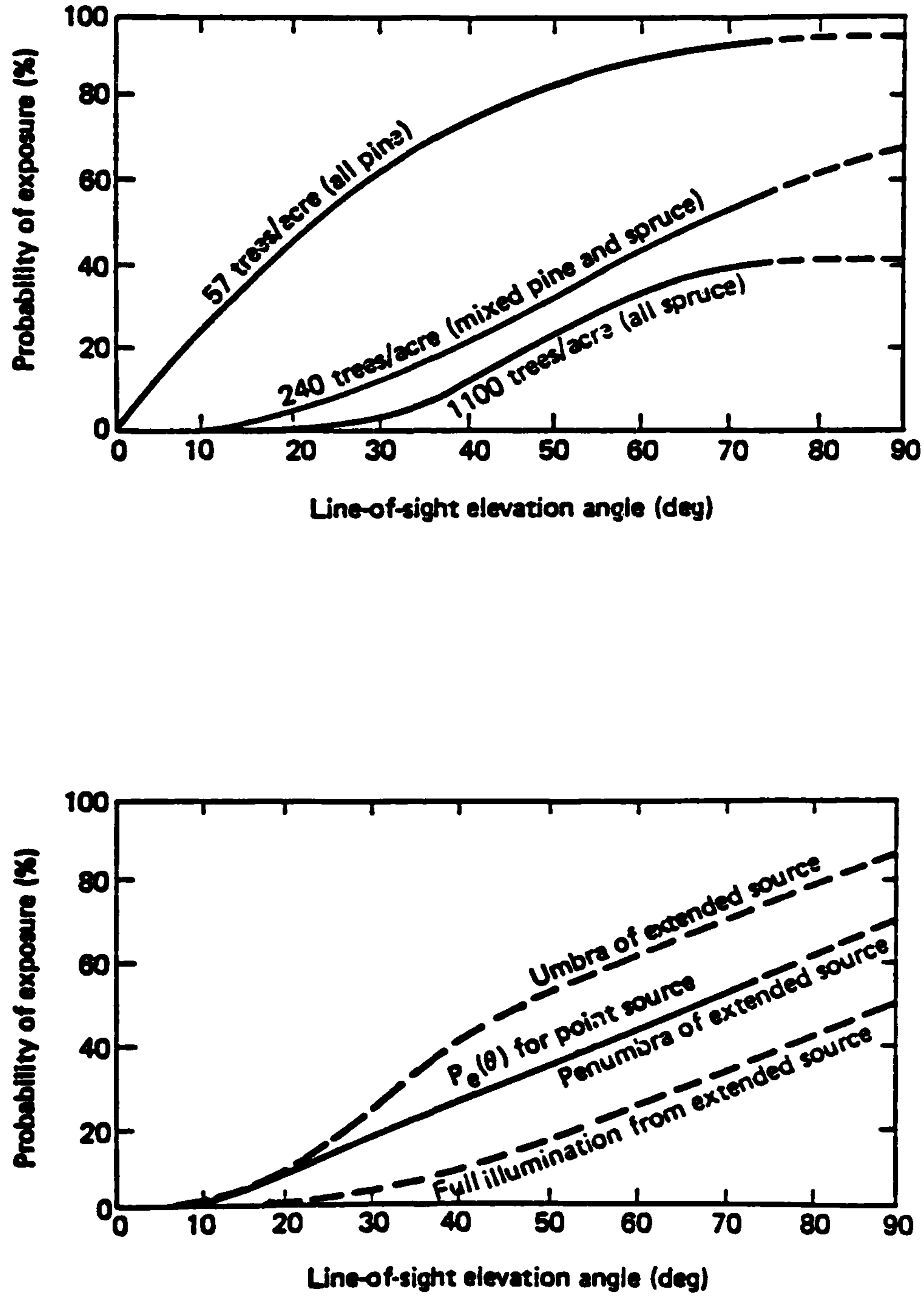
$$Q_{del} = P_e(\theta)\,\frac{W}{\tilde{R}^2}\left(1 + \frac{a\tilde{R}}{V}\right)e^{-b\tilde{R}/V} \quad cal/cm^2 \ , \tag{3}$$

where W is the yield in kilotons, $\tilde{R}$ the slant range in miles, V the visibility lengths in miles, and a, b are dimensionless coefficients that describe the atmospheric albedo and absorption, respectively. Median values are a = 1.5, b = 2.5. The $P_e(\theta)$ accounts for a covering forest canopy and defines the probability of fuel exposure; θ is the elevation angle between the fireball and the horizon.

The probable forest floor exposure depends on tree type, distribution and density, tree foliage condition (season), and tree height. In Kerr et al. [1971], an exposure probability function for a standard northern European forest is described. Figure 2 shows that function for a point source and an extended source fireball with an apparent diameter of 10 deg. For the current version of the TIFS computer model, we have assumed $P_e = 1/2$ for all angles.

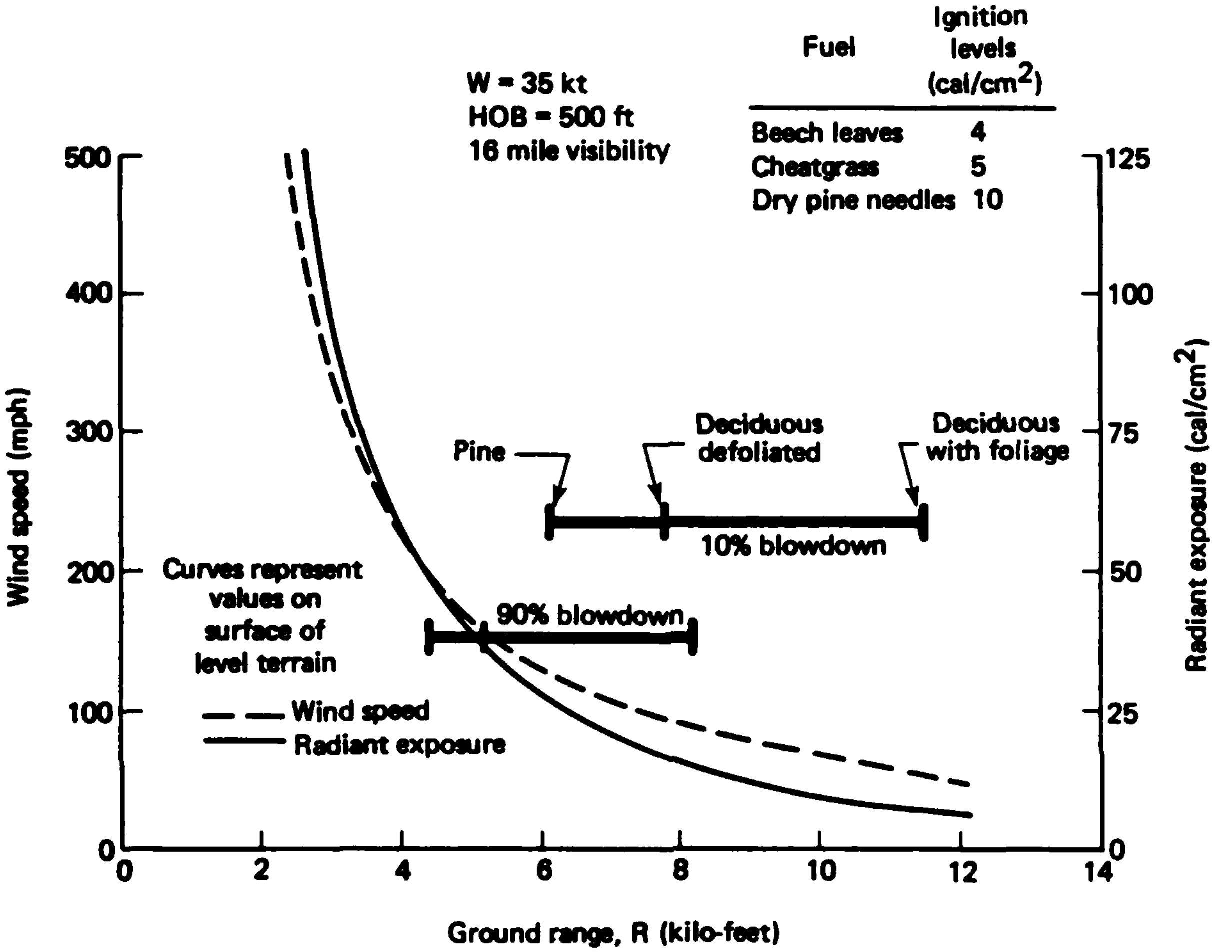
The effect of blast winds on the newly ignited flames is not included in the current model. In several atmospheric tests it was observed that the blast wave extinguished some flames (though not all) [Arnold, 1952]. In general [Smiley, 1980], flame extinction is not expected below about 5 psi (wind speed $\approx$ 100 mph). Figure 3 shows radiant exposure and blast wind speed versus ground range for a 35 KT weapon detonated at a height of 500 ft. The 100 mph level occurs at a ground range of about 8000 ft. The corresponding radiant exposure is about 15 cal/cm^2.

This level of radiant exposure is sufficient to ignite dry fine fuels provided there is no forest canopy, but falls short of the required ignition level when the probability of exposure due to a dense canopy is taken into account. For many field conditions, there are a variety of terrain factors that could modify both the expected wind speed and canopy cover. With enough variety in the forest fuel geometry, many scattered points of sustained ignition could persist even after the blast wave arrival and that some flaming fuels could be transported to unignited areas. If even one point of ignition survives, the possibility of fire spread is preserved.



Source: Kerr et al. [1971].

Figure 2. Probability of forest floor exposure as function of source elevation angle for various conditions of forest canopy.



Source: Kerr et al. [1971].

Figure 3. Blowdown velocities and radiant exposures from 35-KT burst 500 ft above level terrain.

SECTION 3
FIRE SPREAD

There are many parameters that influence the course and rate of a spreading fire. The particular fuel composition, distribution, and loading; weather and its influence on fuel moisture levels; wind and terrain features; all affect the fire intensity and the forward transmission of heat. In general, such parameters are difficult to characterize, and rigorous analysis at best can only calculate spread for simple idealized fuels and geometries.

The U.S. Forest Service fire-spread routines used in TIFS are based on an integral formulation [Fransden, 1971] that relates the quasi-steady propagation of a combustion wave to the forward flux of heat (principally radiative and convective transfer). The methodology developed by Rothermel [1972] and Albini [1976a,b] substitutes in the energy formulation, empirical relations describing complex physical phenomena for analytical terms. Two algebraic relations form the basis of the empirical development. The first treats the reaction intensity of a given fuel, and requires characterization of the effective fuel properties. The second considers the rate of spread and is defined by an energy flux propagation equation that includes the influence of parameters such as wind and slope.

The fire's reaction intensity I_R (the energy released per unit area per unit time in the reaction zone) is proportional to the fuel loading w, the fuel heat content h, and the reaction time τ_R (the time taken for the fire front to travel a distance equivalent to the depth of one reaction zone) by

$$I_R = \frac{wh}{\tau_R} \eta_M \eta_s , \qquad (4)$$

where η_m and η_s are moisture and mineral content damping coefficients. The reaction intensity depends on the fuel, and determines the amount

of energy available for transmission forward to unburned fuel elements. The required coefficients and properties have been measured and cataloged for several fuel models [Anderson, 1982].

The propagating flux I_p (the amount of heat entering the unburned fuel bed per unit area per unit time), the rate of spread R, the effective fuel bulk density ρ_e (the mass per unit volume of fuel involved in the ignition process), and the heat of ignition Q_{ig} are related by

$$R = \frac{I_p}{\rho_e Q_{ig}} (1 + \phi_s + \phi_w) \quad , \tag{5}$$

where the functions ϕ_w and ϕ_s account for the effect of wind and slope. The sum of horizontal and vertical heat fluxes is represented by I_p. Equations (4) and (5) are related by the ratios

$$\varepsilon = \rho_e/\rho_b \quad , \tag{6}$$

and

$$\xi = I_p/I_R \quad , \tag{7}$$

where ρ_b is the fuel bulk density and ξ is the forward heat transmission parameter. The factor ε represents the fraction of fuel heated to ignition and is related to the characteristic surface area to volume ratio σ, for a particular fuel. The transmission parameter ξ is also related (empirically) to fuel parameters such as σ and the "packing ratio" β. For zero wind and slope conditions

$$\xi = \frac{\exp[(0.792 + 0.681\sqrt{\sigma})(\beta + 0.1)]}{192 + 0.259\sigma} \quad . \tag{8}$$

When similar expressions are substituted for ϕ_s and ϕ_w [see Eq. (5)], fire spread for more general conditions can be calculated.

The above equations form the framework of the fire-spread model; the various quantities required are either physical constants related to the fuel or functional fits of experimental data. Multiple fuel classes are included by an appropriate weighting of the parameters. The U.S. Forest Service spread model has been validated in a number of comparisons between predictions and field results [Andrews, 1980].

SECTION 4
SAMPLE CALCULATION

An example problem chosen to demonstrate the utility of TIFS considers a possible tactical encounter in a low, rolling, mountain pass typical of western Europe. In the example, a forested ridge rising from a brush-covered plain is presumed to have an enemy location on its northeast flank. A 10-KT weapon is detonated at a 200 m height of burst. The atmospheric visibility is assumed to be 10 km, and the dead fuel moisture content is assumed to be zero. The initial fire area and its subsequent spread in the battlefield area are the desired outputs.

The terrain and fuel boundaries used as input for the example TIFS calculation are shown in Fig. 4, along with the calculated fire time-of-arrival contours. The source map used for this example contains the information on the forest type (deciduous or evergreen), roadway locations that act as potential firebreaks, and values of local slope (from elevation contours). The variation of direction and magnitude of slope in the forested area are used to define 23 region boundaries (see Fig. 4); in each region slope is assumed constant. In this example, a timber litter with understory fuel model is used for the 23 small forested regions, and a brush fuel model for the large surrounding region. In this version of TIFS, all regions have the same moisture content, but each region has a unique moisture of extinction according to fuel type.

Roadways indicated on the source map are considered potential firebreaks. Since there were many minor roads shown (probably serving as logging or residential roads), only a fraction were used in this calculation. The widths of the roads are not indicated on the source map, and, arbitrary width assignments varying from 4 to 20 m were made. The fire could crosses a break if the tilted flame spans at least one-half the firebreak width in the wind direction [Woodie, Remetch, and Small, 1984]. Only about 10 percent of the firebreaks in

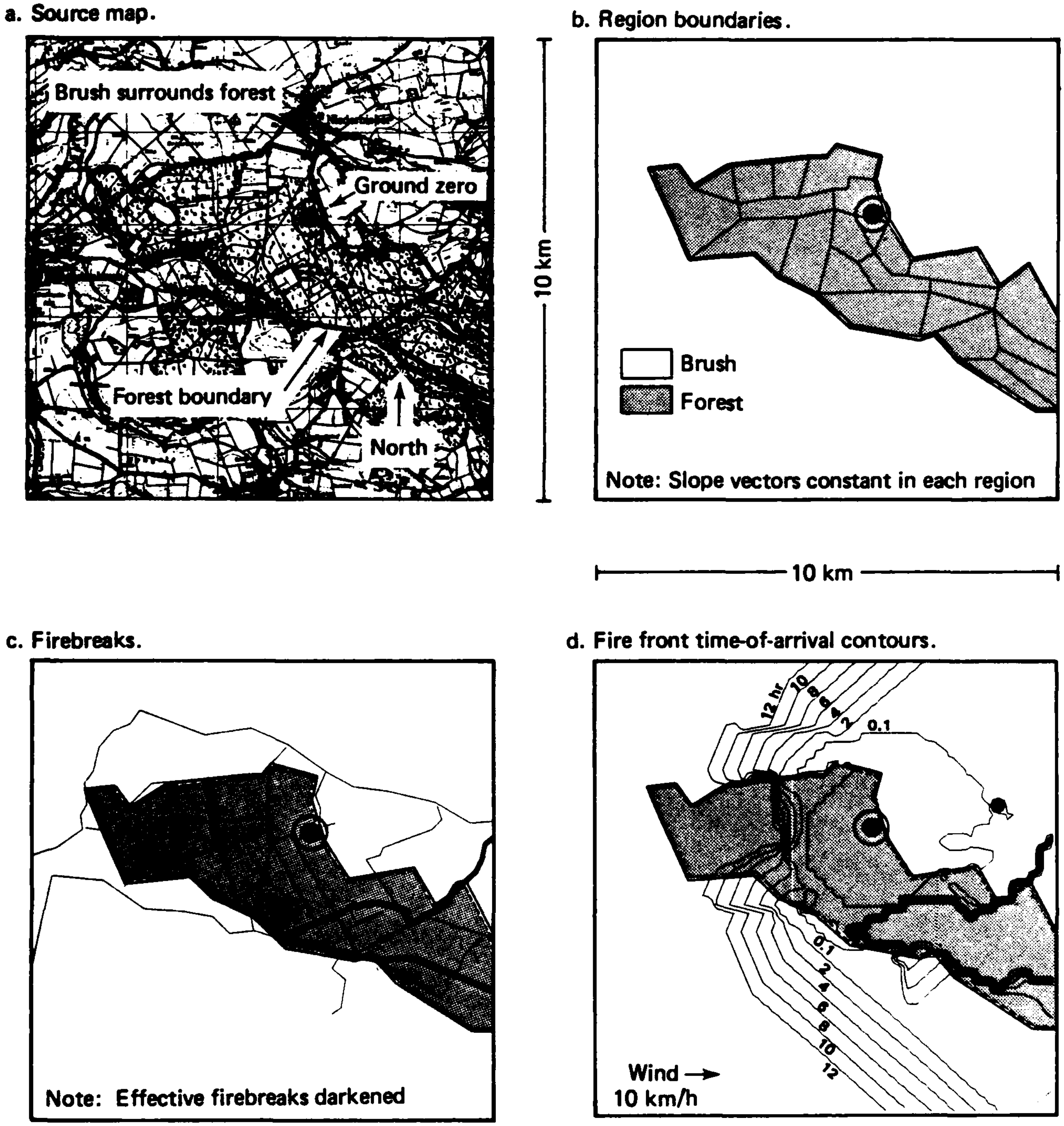


Figure 4. Sample calculation of fire spread resulting from 10-KT detonation over forest region surrounded by brush.

this example were effective in stopping the spread (indicated by the darkened lines).

The results of the fire-spread calculations for the example data are shown in Fig. 4 as fire front time-of-arrival contours. The time (in hours) elapsed since detonation is indicated on each contour line. The contour lines labeled "0.1" approximately outline the initial ignition area from the airburst. Had there been only one fuel type, the ignition area would have been nearly circular. The initial noncircular contour is due to greater ignition ranges for brush than for timber litter, terrain variations, and also the biasing ambient wind.

The fire front time-of-arrival contours shown in Fig. 4 provide a suggestion of possible use in tactical planning. In particular, the results define unburned forest sectors that could be used as friendly strongholds without fire-related limitations. Alternatively, enemy forces in those areas would survive the fire. There were two large sectors that escaped the advancing fire up to 12 h later. One includes the western quarter of the forested area, and the other a wedge-shaped sector covering approximately one-fourth of the forested area on the southeast side. The fire moved more rapidly in the surrounding brush-covered plains, especially in the westerly direction of the wind.

The prediction of safe areas, areas subject to intense burning, and the time for the fire to pass designated sectors suggests that criteria for both optimum weapon employment and troop movements can be developed. In this sample calculation, the fire did not spread to two sectors on the ridge. An alternative detonation point (in the eastern quadrant) would increase the area exposed to fire damage. A slightly larger yield weapon would also extend the range at which primary ignitions occur, thus obviating the firebreak effectiveness.

SECTION 5
CONCLUSIONS

The TIFS algorithm described here allows an estimate of potential fire effects on the nuclear battlefield. Although a first model, the use of well established routines and procedures for prediction of initial ignitions and fire spread provides some confidence in the algorithm. Certainly there are more effects that should be included and other models of effects that could be improved. Nevertheless, at least some statements can be made as to the effect of fire on the tactical battlefield. Future efforts might consider more general or additional fuel models, weather conditions, and terrains and the development of the TIFS algorithm into an operational program.

SECTION 6

LIST OF REFERENCES

Albini, F. A., Computer-Based Models of Wildland Fire Behavior: A Users Manual, U.S. Department of Agriculture, Intermountain Forest and Range Experiment Station, Ogden, Utah, 1976a.

-----, Estimating Wildfire Behavior and Effects, USDA Forest Service, General Technical Report INT-30, Ogden, Utah, 1976b.

Anderson, H. E., Aids to Determining Fuel Models for Estimating Fire Behavior, Intermountain Forest and Range Experiment Station, USDA Forest Service, General Technical Report, INT-122, Ogden, Utah, April 1982.

Andrews, P. A., "Testing the Fire Behavior Model," Proceedings of the Sixth Conference on Fire and Forest Meteorology, [Seattle, Washington, April 22-24], Soc. Am. For., Washington, DC, 1980.

Arnold, K., Effects of Atomic Explosions on Forest Fuels, Operation Snapper, Project 8.1, USDA Forest Service, WT-506, June 1952.

Frandsen, W. H., "Fire Spread through Porous Fuels from the Conservation of Energy," Combust. and Flame, Vol. 16, 1971, pp. 9-16.

Glasstone, S., and P. J. Dolan (eds.), The Effects of Nuclear Weapons, U.S. Department of Defense, Washington, DC, 1977.

Kerr, J. W., et al., Nuclear Weapons Effects in a Forest Environment--Thermal and Fire, Pub. DASIC (DOD Nuclear Information and Analysis Center), (N2 Panel Meeting, November 1969), N2:TR2:70, Defense Nuclear Agency, Washington, DC, July 1971.

Rothermel, R. C., A Mathematical Model for Predicting Firespread in Wildland Fuels, U.S. Department of Agriculture, Intermountain Forest and Range Experiment Station, Ogden, Utah, Research Paper INT-115, January 1972.

Small, R. D., and H. Brode, "Thermal Radiation from a Nuclear Weapon Burst," Proceedings of the 1983 Asilomar Blast/Fire Conference, Pacific Grove, California, June 1983.

Smiley, R. H., Nuclear Weapons Employment in a Forest Environment, Defense Nuclear Agency, Washington, DC, September 1980 (submitted by JAYCOR, Alexandria, Virginia as DNA001-80-C-0086).

Woodie, W. L., D. J. Remetch, and R. D. Small, Nuclear Weapon Effect Research at PSR - 1983, Vol. 2. Fire Spread from Tactical Nuclear Weapons in Battlefield Environments, Pacific-Sierra Research Corporation, PSR Report 1422, July 1984.

DISTRIBUTION LIST

DEPARTMENT OF DEFENSE

ARMED FORCES RADIOBIOLOGY RSCH INST
ATTN: V BOGO

ASSISTANT TO THE SECRETARY OF DEFENSE
ATOMIC ENERGY
ATTN: COL T HAWKINS

DEFENSE INTELLIGENCE AGENCY
ATTN: N BARON
ATTN: RTS-2B

DEFENSE NUCLEAR AGENCY
ATTN: DFRA
ATTN: DFSP G ULLRICH
ATTN: RAAE K SCHWARTZ
ATTN: RAAE L WITTWER
ATTN: RAAE T WALSH
ATTN: RAEE G BAKER
ATTN: RAEE R WEBB
ATTN: SPAS M FRANKEL
ATTN: TDRP D AUTON
ATTN: TDTD/C CORSETTI
4 CYS ATTN: TITL

DEFENSE TECHNICAL INFORMATION CENTER
12 CYS ATTN: DD

NATIONAL DEFENSE UNIVERSITY
ATTN: G FOSTER MOBIL CONCEPTS DEV CTR

OFFICE OF THE SEC OF DEFENSE
ATTN: LTCOL G BETOURNE
ATTN: R RUFFIN

OFFICE OF THE SECRETARY OF DEFENSE
ATTN: COL A RAMSAY

DEPARTMENT OF THE ARMY

NATIONAL WAR COLLEGE
ATTN: COL S GARDINER
ATTN: H ALMOND

U S ARMY ATMOSPHERIC SCIENCES LAB
ATTN: R SUTHERLAND
ATTN: SLCAS-AR-M MR RUBIO

U S ARMY CORPS OF ENGINEERS
ATTN: DAEN-RDM R GOMEZ
ATTN: DR CHOROMOKOS DAEN-RDM

U S ARMY CORPS OF ENGINEERS
ATTN: L ZIEGLER
ATTN: R BECKER

U S ARMY ENGR WATERWAYS EXPER STATION
ATTN: L LINK

U S ARMY MISSILE INTELLIGENCE AGENCY
ATTN: J GAMBLE

U S ARMY NATICK RSCH DEV & ENGRG CENTER
ATTN: H M EL-BISI

U S ARMY STRATEGIC DEFENSE COMMAND
ATTN: DR J LILLY
ATTN: G EDLIN
ATTN: J VEENEMAN
ATTN: M CAPPS
ATTN: R BRADSHAW

DEPARTMENT OF THE NAVY

CNO EXECUTIVE PANEL
ATTN: CAP L BROOKS

NAVAL RESEARCH LABORATORY
ATTN: R JEK

NAVAL SURFACE WEAPONS CENTER
ATTN: K-44 S MASTERS

DEPARTMENT OF THE AIR FORCE

AF/INYXC
ATTN: LTCOL N BARRY

AIR FORCE GEOPHYSICS LABORATORY
ATTN: D CHISHOLM
ATTN: LS/R MURPHY
ATTN: LSI/ H GARDINER
ATTN: LYC/R BANTA
ATTN: LYP H S MUENCH

AIR FORCE INSTITUTE OF TECHNOLOGY/EN
ATTN: AFIT/ENP MAJ S R BERGGREN

AIR FORCE OFFICE OF SCIENTIFIC RSCH
ATTN: D BALL

AIR FORCE OPERATIONAL TEST & EVAL CTR
ATTN: MAJ N RODRIGUES

AIR FORCE SPACE DIVISION
ATTN: YNC CAPT K O'BRYAN

AIR FORCE TECHNICAL APPLICATIONS CTR
ATTN: J MARSHALL

AIR FORCE WEAPONS LABORATORY, NTAAB
ATTN: CAPT LEONG
ATTN: J JANNI
ATTN: J W AUBREY, NTED
ATTN: LT LAHTI
ATTN: LTCOL V BLISS

AIR UNIVERSITY
ATTN: LTCOL F REULE

AIR WEATHER SERVICE, MAC
ATTN: MAJ J SCHLEHER

BALLISTIC MISSILE OFFICE/DAA
ATTN: LT ROTHCHILD
ATTN: MYSP/CAP TOMASZEWSKI

DEPUTY CHIEF OF STAFF/XOX
ATTN: AFXOX

STRATEGIC AIR COMMAND
ATTN: CAP CONNERY

STRATEGIC AIR COMMAND/XPXF
ATTN: T BAZZOLI

DEPARTMENT OF ENERGY

ARGONNE NATIONAL LABORATORY
ATTN: H DRUCKER
ATTN: M WESLEY
ATTN: P BECKERMAN

BROOKHAVEN NATIONAL LABORATORY
ATTN: B MANOWITZ
ATTN: E WEINSTOCK

DEPARTMENT OF ENERGY
ATTN: I NEDDOW
ATTN: T HARRIS

DESERT RESEARCH INSTITUTE
ATTN: J HALLETT
ATTN: J HUDSON

LAWRENCE BERKELEY NATIONAL LAB
ATTN: H ROSEN

UNIVERSITY OF CALIFORNIA
LAWRENCE LIVERMORE NATIONAL LAB
ATTN: C R MOLENKAMP
ATTN: C SHAPIRO
ATTN: F LUTHER
ATTN: G BING
ATTN: G SIMONSON
ATTN: J PENNER
ATTN: J POTTER
ATTN: L-10 A GROSSMAN
ATTN: L-262 A BROYLES
ATTN: L-262 J KNOX
ATTN: L-453 L ANSPAUGH
ATTN: M MACCRACKEN
ATTN: R MALONE
ATTN: R PERRET
ATTN: S GHAN

LOS ALAMOS NATIONAL LABORATORY
ATTN: D SAPPENFIELD
ATTN: E J CHAPYAK
ATTN: E JONES
ATTN: E SYMBALISTY
ATTN: G GLATZMAIER
ATTN: G M SMITH
ATTN: L H AUER
ATTN: L CLOUTMAN
ATTN: P HUGES
ATTN: T YAMATTA

OAK RIDGE NATIONAL LABORATORY
ATTN: D FIELDS

SANDIA NATIONAL LABORATORIES
ATTN: A L JOHNSON
ATTN: B ZAK
ATTN: D DAHLGREN
ATTN: D FORDHAM
ATTN: D WILLIAMS
ATTN: K D BERGERON
ATTN: L TROST
ATTN: M D BENNETT
ATTN: R C BACKSTROM

OTHER GOVERNMENT

CENTRAL INTELLIGENCE AGENCY
ATTN: A WARSHAWSKY
ATTN: 7E47 R NELSON

DEPARTMENT OF AGRICULTURE
ATTN: D HAINES

DEPARTMENT OF TRANSPORTATION
ATTN: COL M ROESCH

ENVIRONMENTAL PROTECTION AGENCY
ATTN: R COTHERN
ATTN: W E FALLON

FEDERAL EMERGENCY MANAGEMENT AGENCY
ATTN: B W BLANCHARD
ATTN: D BENSON NP-CP-MR
ATTN: D KYBAL
ATTN: J POWERS
ATTN: J RUMBARGER
ATTN: S ALTMAN

GENERAL ACCOUNTING OFFICE
ATTN: A PIERCE
ATTN: P J BOLLEA
ATTN: V BIELECKI

NASA
ATTN: N CRAYBILL
ATTN: W R COFER

NASA
ATTN: R HABERLE
ATTN: O TOON
ATTN: R YOUNG
ATTN: T ACKERMAN

NATIONAL BUREAU OF STANDARDS
ATTN: G MULHOLLAND
ATTN: R LEVINE
ATTN: R REHM
ATTN: R SCHRACK

NATIONAL BUREAU OF STANDARDS
ATTN: H BAUM

NATIONAL CENTER ATMOSPHERIC RESEARCH
ATTN: J KIEHL
ATTN: S SCHNEIDER
ATTN: S THOMPSON
ATTN: V RAMASWAMY

NATIONAL CLIMATE PROGRAM OFFICE
ATTN: A HECHT
ATTN: M YERG

NATIONAL OCEANIC & ATMOSPHERIC ADMIN
ATTN: F FEHSENFELD
ATTN: J DELUISI
ATTN: R DICKINSON
ATTN: R PUESCHEL
ATTN: V DERR

NATIONAL OCEANIC & ATMOSPHERIC ADMIN.
ATTN: B HICKS

NATIONAL RESEARCH COUNCIL
ATTN: K BEHR
ATTN: R DEFRIES

NATIONAL SCIENCE FOUNDATION
ATTN: B BEASLEY
ATTN: E BIERLY
ATTN: H VIRJI
ATTN: L HAMATY
ATTN: R SINCLAIR
ATTN: R TAYLOR
ATTN: S KEENY

NUCLEAR REGULATORY COMMISSION
ATTN: R ALEXANDER

OFFICE OF SCIENCE AND TECH POLICY
ATTN: B HEALY
ATTN: COL S WYMAN

OFFICE OF TECHNOLOGY ASSESSMENT
ATTN: R WILLIAMSON

U S ARMS CONTROL & DISARMAMENT AGCY
ATTN: B DOENGES NWC-DPA
ATTN: CDR P JAMISON
ATTN: COL H HERTEL
ATTN: G PITMAN
ATTN: H SCHAEFFER
ATTN: LTCOL S LAWRENCE
ATTN: R GODESKY
ATTN: R HOWES
ATTN: R O'CONNELL NWC-DPA

U S DEPARTMENT OF STATE
ATTN: A CORTE
ATTN: C CLEMENT,(OES.STS)
ATTN: COL M SEATON
ATTN: S CLEARY
ATTN: T VREBALOVICH OES STS

U S GEOLOGICAL SURVEY
ATTN: R DECKER

U S GEOLOGICAL SURVEY
ATTN: E SHOEMAKER

U S HOUSE OF REPRESENTATIVES
ATTN: C BAYER
ATTN: COMMITT ON SCI & TECH J DUGAN

U S HOUSE OF REPRESENTATIVES
ATTN: J FREIWALD
ATTN: M HERBST

US DEPARTMENT AGRICULTURE
ATTN: D WARD

DEPARTMENT OF DEFENSE CONTRACTORS

AERO-CHEN RESEARCH LABS, INC
ATTN: D B OLSON

AERODYNE RESEARCH, INC
ATTN: C KOLB
ATTN: J LURIE

AEROJET ELECTRO-SYSTEMS CO
ATTN: A FYMAT
ATTN: S HAMILTON
ATTN: R PAN

AEROSPACE CORP
ATTN: C RICE
ATTN: L R MARTIN

AEROSPACE CORPORATION
ATTN: G LIGHT

ALLEN RESEARCH CORP
ATTN: R ALLEN

AMERICAN ASSN ADVANCEMENT OF SCIENCE
ATTN: D M BURNS

ANALYTIC SERVICES, INC (ANSER)
ATTN: R BROFFT
ATTN: R ELLINGSON

APPLIED RESEARCH CORP
ATTN: A ENDAL

ASSN. DIST. AMERICAN SCIENTISTS
ATTN: J HUBBARD

AT&T DEFENSIVE SYSTEMS STUDIES
ATTN: R JANOW

ATMOSPHERIC AND ENVIRONMENTAL RES
ATTN: N SZE

AUDIO INTELLIGENCE DEVICES INC
ATTN: H BAUM

AVCO SYSTEMS DIVISION
ATTN: G GRANT, DEPT MGR

BALL AEROSPACE SYSTEMS DIVISION
ATTN: B CUMMINGS
ATTN: C BRADFORD

BDM CORP
ATTN: D SHAEFFER
ATTN: E L COFFEY
ATTN: J LEECH

BERKELEY RSCH ASSOCIATES, INC
ATTN: S BRECHT

BOEING AEROSPACE COMPANY
ATTN: N GERONTAKIS

BOEING TECHNICAL & MANAGEMENT SVCS, INC
ATTN: G HALL

C. L. CONSULTING SERVICES
ATTN: F FEER

CALIFORNIA RESEARCH & TECHNOLOGY, INC
ATTN: M ROSENBLATT
ATTN: R GAJ
ATTN: S KRUEGER

CALSPAN CORP
ATTN: R MAMBRETTI
ATTN: R MISSERT

CARNEGIE CORPORATION OF NEW YORK
ATTN: D ARSENIAN

CASSIDY AND ASSOCIATES
ATTN: J JACOBSON

CHARLES STARK DRAPER LAB, INC
ATTN: A TETEWSKI

COLORADO STATE UNIVERSITY
ATTN: D KRUEGER
ATTN: W COTTON

COMPUTER SCIENCES CORP
ATTN: G CABLE

DARTSIDE CONSULTING
ATTN: A FORESTER

DELTA RESEARCH
ATTN: L WEINER
ATTN: M RADKE

DYNAMICS TECHNOLOGY, INC
ATTN: D HOVE

ENW INTERNATIONAL, LTD
ATTN: J CANE

EOS TECHNOLOGIES, INC
ATTN: B GABBARD
ATTN: N JENSEN
ATTN: W LELEVIER

FACTORY MUTUAL RESEARCH CORP
ATTN: M A DELICHATSIOS

FEDERATION OF AMERICAN SCIENTISTS
ATTN: J STONE

GENERAL ELECTRIC CO
ATTN: R E SCHMIDT

GENERAL ELECTRIC CO
ATTN: H ROBSON

GENERAL RESEARCH CORP
ATTN: B BENNETT
ATTN: J BALTES

HAROLD ROSENBAUM ASSOCIATES, INC
ATTN: G WEBER

HORIZONS TECHNOLOGY INC
ATTN: A EDWARDS
ATTN: J A MANGO
ATTN: J AMBROSE

HORIZONS TECHNOLOGY, INC
ATTN: R W LOWEN
ATTN: W T KREISS

HUGHES AIRCRAFT
ATTN: E DIVITA

INFORMATION SCIENCE, INC
ATTN: W DUDZIAK

INSTITUTE FOR DEFENSE ANALYSES
ATTN: C CHANDLER
ATTN: E BAUER
ATTN: F ALBINI

JOHNS HOPKINS UNIVERSITY
ATTN: M LENEVSKY
ATTN: R FRISTROM
ATTN: W BERL

KAMAN SCIENCES CORP
ATTN: J RUSH
ATTN: J SCRUGGS

KAMAN SCIENCES CORP
ATTN: P GRIFFIN
ATTN: P TRACY

KAMAN TEMPO
ATTN: B GAMBILL
ATTN: D FOXWELL
ATTN: DASIAC
ATTN: E MARTIN
ATTN: R RUTHERFORD
ATTN: R YOUNG
ATTN: S FIFER
ATTN: W KNAPP

KAMAN TEMPO
ATTN: D ANDERSON
ATTN: DASIAC

LOCKHEED MISSILES & SPACE CO, INC
ATTN: ATTN J HENLEY
ATTN: J GLADIS
ATTN: J PEREZ

LOCKHEED MISSILES & SPACE CO, INC
ATTN: P DOLAN
ATTN: W MORAN

M I T LINCOLN LAB
ATTN: S WEINER

MARTIN MARIETTA DENVER AEROSPACE
ATTN: D HAMPTON

MAXIM TECHNOLOGIES, INC
ATTN: J MARSHALL

MCDONNELL DOUGLAS CORP
ATTN: R C ANDREWS
ATTN: T CRANOR
ATTN: T TRANER

MCDONNELL DOUGLAS CORP
ATTN: A MONA
ATTN: F SAGE
ATTN: G BATUREVICH
ATTN: J GROSSMAN
ATTN: R HALPRIN
ATTN: S JAEGER
ATTN: W YUCKER

MERIDIAN CORP
ATTN: E DANIELS
ATTN: F BAITMAN

MIDWEST RESEARCH INSTITUTE
ATTN: J S KINSEY

MISSION RESEARCH CORP
ATTN: R ARMSTRONG

MISSION RESEARCH CORP
ATTN: C LONGMIRE
ATTN: D ARCHER
ATTN: D KNEPP
ATTN: D SOWLE
ATTN: F FAJEN
ATTN: K R COSNER
ATTN: M SCHEIBE
ATTN: R BIGONI
ATTN: R CHRISTIAN
ATTN: R GOLDFLAM
ATTN: R HENDRICK
ATTN: T OLD
ATTN: W WHITE

MITRE CORPORATION
ATTN: J SAWYER

MRJ INC
ATTN: D FREIWALD

NATIONAL ADVISORY COMMITTEE
ATTN: J ALMAZAN
ATTN: J BISHOP

NATIONAL INST. FOR PUBLIC POLICY
ATTN: K PAYNE

NICHOLS RESEARCH CORP, INC
ATTN: H SMITH
ATTN: J SMITH
ATTN: M FRASER
ATTN: R BYRN

NORTHROP SERVICES INC
ATTN: T OVERTON

ORLANDO TECHNOLOGY INC
ATTN: R SZCZEPANSKI

PACIFIC-SIERRA RESEARCH CORP
2 CYS ATTN: D REMETCH
ATTN: G ANNO
ATTN: H BRODE, CHAIRMAN SAGE
ATTN: M DORE
2 CYS ATTN: R SMALL
2 CYS ATTN: W WOODIE

PALOMAR CORP
ATTN: B GARRETT
ATTN: C FELDBAUM

PHOTOMETRICS, INC
ATTN: I L KOFSKY

PHOTON RESEARCH ASSOCIATES
ATTN: J MYER

PHYSICAL RESEARCH CORP
ATTN: A CECERE

PHYSICAL RESEARCH INC
ATTN: H FITZ

PHYSICAL RESEARCH INC
ATTN: D MATUSKA

PHYSICAL RESEARCH INC
ATTN: A WARSHAWSKY
ATTN: J WANG
ATTN: W SHIH

PHYSICAL RESEARCH INC
ATTN: R JORDANO

PHYSICAL RESEARCH, INC
ATTN: D WESTPHAL
ATTN: D WHITENER
ATTN: H WHEELER
ATTN: R BUFF
ATTN: R DELIBERIS
ATTN: T STEPHENS
ATTN: W C BLACKWELL

PHYSICAL RESEARCH, INC
ATTN: G HARNEY
ATTN: J DEVORE
ATTN: J THOMPSON
ATTN: R STOECKLY
ATTN: W SCHLEUTER

PHYSICAL RESEARCH, INC
ATTN: H SUGIUCHI

POLYTECHNIC OF NEW YORK
ATTN: B J BULKIN
ATTN: G TESORO

PRINCETON UNIVERSITY
ATTN: J MAHLMAN

QUADRI CORP
ATTN: H BURNSWORTH

R & D ASSOCIATES
ATTN: A KUHL
ATTN: F GILMORE
ATTN: G JONES
ATTN: J SANBORN
ATTN: R TURCO

R & D ASSOCIATES
ATTN: B YOON

R J EDWARDS INC
ATTN: R SEITZ

RADIATION RESEARCH ASSOCIATES, INC
ATTN: B CAMPBELL
ATTN: M WELLS

RAND CORP
ATTN: G L DONOHUE
ATTN: P ROMERO

RAND CORP
ATTN: J GERTLER

ROCKWELL INTERNATIONAL CORP
ATTN: S I MARCUS

ROCKWELL INTERNATIONAL CORP
ATTN: J KELLEY

S-CUBED
ATTN: B FREEMAN
ATTN: K D PYATT, JR
ATTN: R LAFRENZ

S-CUBED
ATTN: C NEEDHAM
ATTN: S HIKIDA
ATTN: T CARNEY

SCIENCE APPLICATIONS INC
ATTN: R EDELMAN

SCIENCE APPLICATIONS INTL CORP
ATTN: C HILL

SCIENCE APPLICATIONS INTL CORP
ATTN: D HAMLIN

SCIENCE APPLICATIONS INTL CORP
ATTN: B MORTON
ATTN: B SCOTT
ATTN: D SACHS
ATTN: G T PHILLIPS
ATTN: J BENGSTOM

SCIENCE APPLICATIONS INTL CORP
ATTN: D BACON
ATTN: DR L GOURE
ATTN: F GIESSLER
ATTN: J COCKAYNE
ATTN: J SHANNON
ATTN: J STUART
ATTN: M SHARFF
ATTN: W LAYSON

SCIENCE APPLICATIONS INTL CORP
ATTN: J SONTOWSKI

SCIENCE APPLICATIONS INTL CORP
ATTN: T HARRIS

SCIENTIFIC RESEARCH ASSOC, INC
ATTN: B WEINBERG

SPARTA INC
ATTN: R HARPER

SRI INTERNATIONAL
ATTN: C WITHAM
ATTN: D GOLDEN
ATTN: D MACDONALD
ATTN: D ROBERTS
ATTN: E UTHE
ATTN: G ABRAHAMSON
ATTN: J BACKOVSKY
ATTN: W CHESNUT
ATTN: W JOHNSON

SRI INTERNATIONAL
ATTN: R BRAMHALL
ATTN: R WOOLFOLK
ATTN: W VAIL

STAN MARTIN ASSOCIATES
ATTN: S B MARTIN

STANTON CONSULTING
ATTN: M STANTON

SWETL, INC
ATTN: T Y PALMER

SYSTEM PLANNING CORP
ATTN: J SCOURAS
ATTN: M BIENVENU
ATTN: R SCHEERBAUM

SYSTEMS AND APPLIED SCIENCES CORP
ATTN: M KAPLAN

TECHNOLOGY INTERNATIONAL CORP
ATTN: W BOQUIST

TELEDYNE BROWN ENGINEERING
ATTN: D ORMOND
ATTN: F LEOPARD
ATTN: J FORD

TELEDYNE BROWN ENGINEERING
ATTN: D GUICE

TEXAS ENGR EXPERIMENT STATION
ATTN: W H MARLOW

TOYON RESEARCH CORP
ATTN: C TRUAX
ATTN: J GARBARINO
ATTN: J ISE

TRW
ATTN: H BURNSWORTH
ATTN: J BELING

TRW ELECTRONICS & DEFENSE SECTOR
ATTN: F FENDELL
ATTN: G KIRCHNER
ATTN: G MROZ
ATTN: H CROWDER
ATTN: J FEDELE
ATTN: M BRONSTEIN
ATTN: R BACHARACH
ATTN: S FINK
ATTN: T NGUYEN

TRW ELECTRONICS & DEFENSE SECTOR
ATTN: M HAAS

VISIDYNE, INC
ATTN: H SMITH
ATTN: J CARPENTER

WASHINGTON, UNIVERSITY OF
ATTN: J I KATZ

FOREIGN

AERE ENVIRONMENTAL AND MEDICAL SC
ATTN: S PENKETT

ATOMIC WEAPONS RESEARCH ESTABLISHMENT
ATTN: P F A RICHARDS

ATOMIC WEAPONS RESEARCH ESTABLISHMENT
ATTN: D L JONES
ATTN: D M MOODY

AUSTRALIA EMBASSY
ATTN: DR LOUGH
ATTN: MAJ GEN H J COATES
ATTN: P PROSSER

BRITISH DEFENCE STAFF
ATTN: C FENWICK
ATTN: J CRANIDGE

ATTN: J EDMONDS
ATTN: M NORTON
ATTN: P WEST

CANADIAN FORESTRY SERVICE
ATTN: B STOCKS
ATTN: T LYNHAM

CSIRO
ATTN: I GALBALLY

CSIRO: ATMOSPHERIC RESEARCH
ATTN: A PITTOCK

EMBASSY OF BELGIUM
ATTN: L ARNOULD

ISRAEL EMBASSY
ATTN: N BELKIND

MAX-PLANCK INSTITUTE FOR CHEMISTRY
ATTN: P J CRUTZEN

MINISTRY OF DEFENCE
ATTN: R RIDLEY

NATIONAL DEFENCE HEADQUARTERS
ATTN: H A ROBITALLE

TRINITY COLLEGE
ATTN: F HARE

DIRECTORY OF OTHER

ATMOS. SCIENCES
ATTN: G SISCOE

BROWN UNIVERSITY
ATTN: R K MATTHEWS

BUCKNELL UNIVERSITY
ATTN: O ANDERSON

CALIFORNIA, UNIVERSITY
ATTN: R WILLIAMSON

CALIFORNIA, UNIVERSITY OF
ATTN: L BADASH/DEPT OF HISTORY

COLORADO, UNIVERSITY LIBRARIES
ATTN: J BIRKS
ATTN: R SCHNELL

DREXEL UNIVERSITY
ATTN: J FRIEND

DUKE UNIVERSITY
ATTN: F DELUCIA

GEORGE MASON UNIVERSITY
ATTN: PROF S SINGER
ATTN: R EHRLICH

GEORGE WASHINGTON UNIVERSITY
ATTN: R GOULARD

GEORGIA INST OF TECH
ATTN: E PATTERSON

HARVARD COLLEGE LIBRARY
ATTN: W PRESS

HARVARD UNIVERSITY
ATTN: G CARRIER

HARVARD UNIVERSITY
ATTN: D EARDLEY

IOWA, UNIVERSITY OF
ATTN: HISTORY DEPT/S PYNE

MARYLAND UNIVERSITY OF
ATTN: A ROBOCK DEPT METEOROLOGY
ATTN: A VOGELMANN DEPT METEOROLOGY
ATTN: R ELLINGSON DEPT METEOROLOGY

MIAMI LIBRARY UNIVERSITY OF
ATTN: C CONVEY

MIAMI UNIV LIBRARY
ATTN: J PROSPERO ATMOS SC

NEW YORK STATE UNIVERSITY OF
ATTN: R CESS

OAK RIDGE ASSOCIATED UNIVERSITIES
ATTN: C WHITTLE

PENNSYLVANIA STATE UNIVERSITY
ATTN: D WESTPHAL

SOUTH DAKOTA SCH OF MINES & TECH LIB
ATTN: H ORVILLE

TENNESSEE, UNIVERSITY OF
ATTN: K FOX

UNIVERSITY OF SOUTH FLORIDA
ATTN: S YING

UNIVERSITY OF WASHINGTON
ATTN: C LEOVY
ATTN: L RAOKE
ATTN: P HOBBS

VIRGINIA POLYTECHNIC INST LIB
ATTN: M NADLER

WASHINGTON STATE UNIVERSITY
ATTN: DR A CLARK

WISCONSIN UNIVERSITY OF
ATTN: P WANG

END
11-87
DTIC